Technology for Training Creative Graduates in Engineering Bachelor's Programs

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Abstract. This article is devoted to technologies of engineering education that produce the most in-demand professional qualities of graduates from Bachelor's programs. A review of studies about introducing innovations to improve the educational process in practice-oriented Bachelor's studies is carried out. The advantages and limitations of project-based and problem-based learning technologies are defined. The work presents the experience of developing and applying a unique teaching technology based on the integration of problem- and project-based training approaches, designed to enhance the creativity of the study process in engineering Bachelor's programs. It is described with a focus on the mechanisms for the integrated use of the advantages of methods of problem- and project-based training in the formation of the professional competencies required for an engineer's innovative activity in the development of a new product project. The data from an empirical study have been considered; they allow us to substantiate the conclusion that the integration of project- and problem-based learning in the form of a holistic technology is effective for developing students' creative capacities.

Keywords: engineering education; engineering Bachelor's programs; project-based learning; problem-based learning; integration of educational technologies; creative capacities

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Introduction

It should be admitted that the majority of engineering academic programs at universities are aimed at training qualified specialists in terms of their content and methodology of implementation. In general, we teach students to complete the assigned tasks; still, when they start their professional career, they often face the practical problem of assigning tasks, developing technical specifications and searching for new effective solutions that should be in line with increasing customer demand. Thus, the main purpose of the development of engineering education should be the improvement of the study process so as to produce creative and conceptual thinking skills and help students to see into problematic situations, formulate problems correctly, transform them into tasks and form original approaches towards their solution. According to the authors, the main means of forming creative capabilities of students is not the content of the study program, but the methods and technologies of the study process, including the organization of educational and practical activities.

Analysis of priority technologies in engineering education

Most attention in higher engineering education is now devoted to the active development of project-based learning methods. By *project-based learning* we mean study and practical work based on solving project tasks and/or implementing a specific project that corresponds to study goals and leads to the achievement of the necessary learning outcomes. Project-based learning is characterized by a number of advantages, recognized by education practitioners and researchers in specific academic disciplines, modules and study programs [1–4]. Among the most frequently mentioned advantages of the project-based learning, there are:

– increased motivation for study and individual work;

– stimulating the interdisciplinary approach;

– in-depth understanding of the importance of theoretical academic issues for the solution of relevant professional tasks;

– intensifying the study process and accelerating the formation of professional competencies;

– increasing student responsibility for the results of learning and project activities, and study activities in general;

– developing communication skills and qualities, as well as team working skills.

Project-based learning has been being actively applied at technical universities of many countries. This method is widely used in engineering Bachelor's disciplines, primarily in courses related to design and engineering activities; it significantly develops cognitive abilities and improves self-efficacy, teamwork and communication skills [5]. Project-based learning contributes to the formation of an interactive team learning environment that positively affects learning outcomes and the self-regulation of students [6]. This teaching method is successfully applied not only in purely engineering disciplines, but also in those that provide a foundation of general technical competencies. This is particularly in the teaching of physics, where it has resulted in increased student interest not only in the subject itself, but also in its technological applications [7]. The use of project-based learning in chemistry also enhances student interest and the mastery of the basics of chemical and petroleum engineering: furthermore, it contributes to the fact that they quickly learn to build relationships and form teamworking, leadership and cooperation skills when solving engineering and chemical problems [8]. The project-based learning method has been applied to the teaching of the natural sciences and other disciplines [9; 10].

However, project-based learning has also certain limitations which are largely determined by additional requirements towards learning activities and the facts that most students perceive such learning methods as relatively new and their place in the teaching program, when compared to traditional teaching methods, is generally rather limited. These limitations include: 1) increasing the labor intensity of the academic work aimed at mastering project activities and, thus, a slower process of mastering the curriculum; 2) only a partial correspondence of student educational and project activities to the professional design and engineering activities of engineers; 3) the insufficiently profound and well-grounded design solutions developed by the majority of students; and 4) the detachment of educational project work from research. At the same time, in the majority of works based on empirical studies, it is not noted that it actively develops creative thinking and capabilities. These conclusions fully coincide with the authors' experience of applying the project-based learning approach.

Another method actively used in improving engineering education is *problem-based learning*. It should be noted that this is less popular than the project-based one. According to the authors, the problem-based learning method is the organization of student activities in accordance with an analysis of objective contradictions in scientific knowledge that forms the principal content of the study process; in the course of these activities, students assess the possibility of using previously acquired knowledge and the necessity of acquiring new knowledge to solve problematic situations and specific tasks. As a result, they search for new knowledge and ways of using it that are aimed at reinterpretation, specification and problem solving. Different specialists demonstrate different approaches towards the substance of this method [11–18], though all of them acknowledge the principal benefits of project-based learning. The problem-based method allows students:

– to analyze problematic situations arising from the deficiencies of the knowledge applied;

– to formulate problems and tasks, allowing them to find ways to solve controversies;

– to summarize knowledge, principles and ways of applying them to solve problems and tasks;

– to carry out the search for necessary knowledge in the course of mastering scientific notions;

– to form goal-setting and problematization skills in the course of scientific cognition;

– to boost cognitive activity in the search for effective ways and methods of acting in uncertain conditions and situations;

– to master basic elements of research activity.

In combination with the traditional approach, problem-based learning is deemed an effective means for the general and intellectual development of students at different levels of mastering different academic programs. In the work by Ayyildiz and Tarhan [15], a comparison of the effectiveness of applying traditional and the problem-based learning approaches to chemistry is presented. On the basis of the results obtained by the authors, it was concluded that the average results of the group learning through the problem-based approach were much higher. In the works by X. Ma et al. [16] and A. Shishigu et al. [17], a successful practice of introducing the problem-based learning approach in the training of IT-specialists and teachers was presented. The authors demonstrated that problem-based learning allows for a better understanding of the relationship between theory and practice, increases student motivation and eliminates rote memorization. The article by M.A. Khoiry et al. [19] describes the method of assessing the quality of training in a course on material technology by employing the problem-based learning approach. It was shown that the technology of problem-based learning could be improved by receiving feedback throughout the period of study.

In the work by C. Veale et al. [20], the authors discuss the blending of problem-based learning and student teamwork, which was aimed at forming the creative ideas necessary for the development of advanced medicines: they note that such a type of learning requires the transformation of the whole study program.

In the studies of G.I. Ibragimov [14], it is underlined that the "problematic" character has become a standard practice in professional activities under the present cultural conditions. This leads to the conclusion that in modern higher education, especially in a technical one, problem-based learning should be considered as a basic type of education, a kind of a systemic foundation that allows one to integrate the possibilities and technologies of education, as well as to implement ideas of practical orientation.

It is of interest to study the experience of integrating project-based learning and problem-based learning approaches in the development of academic courses aimed at the formation of competencies necessary for the sustainable development of specific organizations and areas of activity. A course in environmental studies developed for a Master's program created additional opportunities in the development of interdisciplinarity and boosted a proactive attitude towards education, academic studies and professional practice. During the course, the students increased the sustainability of their competencies and professional skills and used opportunities for carrying out research in collaboration with their lecturers [9].

Existing trends for the integration of problem- and project-based learning are determined by the desire to combine the advantages of these methods and thereby overcome the limitations that exist in each of them. A limitation of the creative activity of students working in accordance with the project-based learning method is the fact that they work in the framework of the studied issues and the project task offered by a lecturer or chosen by them. Analysis of problems and tasks solved in the course of such design activities is limited, as the main efforts are targeted at the application of already gained

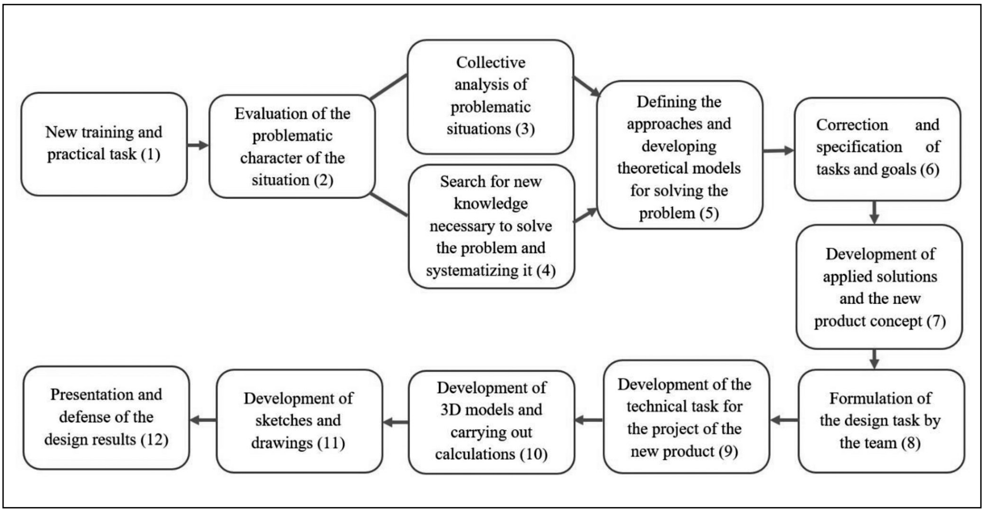

Fig. 1. Model of training and practical activity based on the binary technology

and independently found knowledge related to this discipline. The depth of their studies and the creativity of solutions definitely depend on this knowledge, but these characteristics of design activities largely depend on the level of understanding of the problem (which is always interdisciplinary).

Binary technology in engineer training

The integration of problem- and project-based approaches ("Binary technology") was developed by the authors for the organization of student academic and practical activities in a special *industrial training practical course* (ITPC). The variant presented for integrating the two methods is not only about consolidating them into a larger instrument for organizing the study process, but is also about maintaining the relative independence of problem-based and project-based approaches, along with their benefits. The integration of these two methods results in the extension of the methodological instrument and in the algorithmization of study and practical work while maintaining opportunities for creativity when achieving the necessary results. Binary technology increases the level of student self-discipline and strengthens the benefits of the integrated methods: problem-based learning becomes more practice-oriented, while project-based learning starts to employ deeper research and analytical grounding. The general framework of the binary technology, including its main steps, is presented in *Figure 1*.

The difference between the integration of problem-based and project-based learning through binary technology and its other variants [8; 9] lies in the fact that students work with one complex object that includes many components throughout their activities.

The integration of problem-based and project-based learning rests upon combining them into one problem to solve another problem (creation of an engineering project of a new technical product) and developing an algorithm for its implementation including: a) working on the problem in order to develop theoretical solutions for the problematic situation (steps 2–5, Fig. 1); b) adapting the results of the research and analytical work to the problems of design and engineering activity (steps 6–8, Fig. 1); c) a design process with the further project defense (steps 9–12, Fig. 1).

The presented binary technology differs from other blended learning technologies by the following features.

1. Students are involved in more analytical and research activities, especially during the first semesters, when they have not yet started

studying specialized courses: they thus have to search for the necessary knowledge independently.

2. Designing each product is carried out as a particular part of a more complex technical system; development of this system is an output. This leads to some extra requirements for each product, as it is necessary to integrate them with the other projects forming the system.

3. Students keep on switching from the problem-based to the project-based method and back, trying to find a decision that better corresponds with the requirements of a specific product and its compatibility with other parts of the end product. In the course of this process, students often recognize their own mistakes, the limitations of some solutions, and existing systemic problems: they learn to find ways of coping with them.

4) The design process is as close as possible to the production process of an industrial enterprise and takes into account all the conditions of uncertainty, customer requirements (the consulting engineers perform as customers here), deadlines, regulatory documentation, etc.

5) The binary technology significantly changes the character of the participants' activity. The functions of lecturers, who are not only staff members of the university but also highly qualified engineers in machine-building enterprises, are consulting and tutoring.

6) At each stage of the technology, methodological techniques and means to regulate and boost student activities are used.

It is important to note that study and practical work based on the binary technology are organized so that engineering tasks solved within its framework are reflected in the content of the disciplines studied by the students in the same period. In contrast to the traditional study process, mastering the program is not only a preparation for further professional activities, but also a necessary condition for solving current training and practical engineering tasks set within the framework of the practical course, which increases the proactive attitude and purposefulness of their actions [21].

Results of empirical studies on the possibilities of the binary technology

To assess the benefits and effectiveness of the binary technology, we carried out a student survey to compare their learning activity in the framework of the practical course, which actively employed this technology, with the other engineering discipline which implemented project-based learning methods and other interactive techniques. The main methodological difference between these disciplines is that the industrial training practical course is mainly based on binary technology, while in the course of Engineering Mechanics (EM), the project-based learning was predominantly used. In the training schedule, disciplines were taught in parallel. The volume of students' educational work in the training courses was the same (144 academic hours), including the volume of independent academic work (80–88 educational hours). The study was carried out among the students of the engineering Bachelor's program "System analysis and management" who are majoring in design and engineering and studied the compared disciplines during two semesters. The survey was a self-report; the students evaluated their actions, efforts and attitudes towards the study process in the frameworks of different disciplines employing the aforementioned technologies.

The developed questionnaire employs a nominal scale with partially closed questions; the majority are menu questions with polyvariant responses and control questions, which are required in order to check the sustainability and the univocacy of the respondents' opinions.

More than 68% of the students of the academic groups concerned took part in the voluntary survey. Thus, we received six results from the surveys of academic groups (from 11 to 15 questionnaires in each, 82 in total) The results of the surveys as primary statistics are presented in *Table 1*. The secondary statistical analysis was carried out with the Mann–Whitney U test [22] to assess the difference between the average values of the number of students choosing the specific indicators of study and practical ac-

Table 1

Differences in the results of students' independent educational and practical work in ITPC и EM (%)

Characteristics of independent educational and practical work of students	ITPC	EM
1. Systematization of new knowledge	28,6**	4,8
2. Search for and use of new information unrelated to the academic disciplines	38,1*	23,8
3. Becoming acquainted some specific issues of the disciplines that have not been studied yet	23,8**	4,8
4. Optimizing task performance	38,1**	14,3
5. Skills of solving new (original) problems	47,6*	28,6
6. Development of self-education skills	52,4*	33,3
7. Development of system analysis and thinking skills	38,1**	9,5
8. Development of creative capabilities	33,3**	9,5
9. Ability to navigate complex engineering tasks	29,1*	14,7
10. Use of knowledge gained in lectures and practical classes	9,5	47,6**
11. Skills of solving typical problems	14,3	47,6**
12. Use knowledge from previously studied topics	38,1	61,9**

Note. The detected statistically relevant differences at the level of confidence of 95% are indicated by one asterisk and at the level of confidence of 99% by two asterisks.

tivity (N, %) obtained in different studies (in six questionnaires of academic groups).

The analysis of the data presented in the table shows that students working on the basis of the binary technology search for new information and employ it more actively. The content of the learning activities has a pronounced interdisciplinary nature; they use not only information related to different academic disciplines, but also information from beyond the framework of the study plan (Table 1, point 2). To perform training and practical tasks, they combine knowledge from different subject areas, disciplines and research fields. It is no coincidence that work based on the binary technology requires systematization of new knowledge (Table 1, point 1).

Conditions mentioned in points 3 and 4 are much more important for work based on the binary technology than for work based on traditional project learning technology. These are factors of exceptional importance for efficiency of the practice-oriented learning and the formation of the skills of creative activity. It is necessary to note the importance of the condition "optimizing task performance" (Table 1, point 4), which means not only finding the solution, but also optimizing it in accordance with the requirements of the next stage.

From the analysis of these indicators, it also follows that the range of searching for new information in independent work based on the binary technology is much wider, as it includes the specific issues and topics of disciplines that are planned for the later stages of the study plan (Table 1, point 3). These elements of forward-looking learning form independence, responsibility, creativity and other qualities important for the engineering profession.

In Table 1 (points 5–8), we can see how the students assess the level at which their self-guided work influences feelings of confidence and readiness for further professional activities. The analysis of these data demonstrates that the binary technology actively forms the skills required for solving new (original) problems (Table 1, point 5); in contrast, it has a very slight impact on forming the skills for solving typical problems (Table 1, point 11). The most substantial difference was observed in the evaluation of the influence of study and practical work on the development of creative capabilities (Table 1, point 8) (by more than 3.5 times) and on the development of system analysis and thinking (Table 1, point 7) (by more than 4 times). Work based on the binary technology actively influences the development of self-education skills (Table 1, point 6), and ability to navigate complex engineering tasks (Table 1, point 9). Development of these skills and qualities makes students confident about their capacity to carry out professional activities.

The study also revealed the strengths of traditional project-based training used in the course on EM, which include: a) the ability to use lecture notes and practical exercises (Table 1, point 10); b) the ability to solve typical tasks (Table 1, point 11); c) possession of the content of previously studied topics (Table 1, point 12). These indicators are important for effective learning activities and mastering the content of the discipline. But in this study, they were not directly related to the development of creative abilities.

Conclusion

The indicated advantages of binary technology, which are well demonstrated by the difference in the indicators obtained are among the most in-demand qualities of modern engineers. Graduates who have an experience of study and practical work based on binary technology are more active and independent when solving complicated tasks. They are more prepared to analyze problems, set goals, carry out expanded searches for and system analysis of the necessary information and use it for the development of constructive solutions.

Using binary technology for the practical training of bachelor's students and to prepare them for engineering activities increases the level of their creative activity and thus allows them to develop the abilities necessary for the development and production of innovative products.

Thus, on the basis of the obtained data we can conclude that the developed variant of the blended technology in the form of integrated problem-based and project-based learning provides the achievement of study goals and develops creative capacities in professional activity. According to the authors, students learning on the basis of this technology tend to be proactive, think unconventionally, search for new information and develop original solutions.

References

1. Petruneva, R.M., Toporkova, O.V., Vasilyeva, V.D. (2015). Project-Based Training as a Modern Trend in Engineering Education. *Vysshee obrazovanie v Rossii = Higher Education in Russia.* No. 7, pp. 30-35. (In Russ., abstract in Eng.)
2. Ziyatdinova, Y.N., Sanger, F.A. (2015). Project Based Learning for Training the XXI Century Engineer. *Vysshee obrazovanie v Rossii = Higher Education in Russia.* No. 3, pp. 92-97. (In Russ., abstract in Eng.)
3. Sazonova, Z.S., Arifullin, I.V., Feofanova, L.S., Sherbakova, V.L. (2015). Project-Oriented Learning in the Context of Student Life. *Vysshee obrazovanie v Rossii = Higher Education in Russia.* No. 11, pp. 114-118. (In Russ., abstract in Eng.)
4. Ignatova, I.G., Balashov, A.G., Sokolova, N.Y. (2014). Interdisciplinary Projects as a Method of Competence Building in the Process of Educational Programs Realization. *Vysshee obrazovanie v Rossii = Higher Education in Russia.* No. 5, pp. 86-92. (In Russ., abstract in Eng.)
5. Fini, E.H., Awadallah, F., Parast, M.M., Abu-Lebdeh, T. (2018). The impact of project-based learning on improving student learning outcomes of sustainability concepts in transportation engineering courses. *European Journal of Engineering Education.* No. 43 (3), pp. 473-488.
6. Lin, J.-W. (2018). Effects of an online team project-based learning environment with group awareness and peer evaluation on socially shared regulation of learning and self-regulated learning. *Behaviour and Information Technology.* No. 37 (5), pp. 445-461.
7. Bonanno, A., Bozzo, G., Sapia, P. (2018). Physics meets fine arts: a project-based learning path on infrared imaging. *European Journal of Physics.* No. 3 (2), pp. 025805.
8. Elmore, B.B. (2017). Integrating problem-based and project-based learning in large enrollment freshman engineering courses. In: *ASEE Annual Conference and Exposition.* Columbus. US. 25-28 June 2017.
9. Kricsfalusy, V., George, C., Reed, M.G. (2018). Integrating problem- and project-based learning opportunities: assessing outcomes of a field course in environment and sustainability. *Environmental education research.* No. 24 (4), pp. 593-610.
10. Raycheva, R.P., Angelova, D.I., Vodenova, P.M. (2017). Project-based learning in engineering de-

sign in Bulgaria: expectations, experiments and results. *European Journal of Engineering Education*. No. 42 (6), pp. 944-961.
11. Okon, V. (1990). *Vvedenie v obshchuyu didaktiku* [Introduction to General Didactics]. Moscow: Vyshaya shkola Publ., 381 p. (In Russ.)
12. Makhmutov, M.I. (1998). *Problemnoe obuchenie. Entsiklopediya professional'nogo obrazovaniya* [Problem-based Learning. Encyclopedia of Professional Education]. Moscow: APO Publ., 1784 p. (In Russ.)
13. Kudryavtsev, V.T. (1991) *Problemnoe obuchenie: istoki, sushchnost', perspektivy* [Problem-based Learning: Origins, Substance, Prospects]. Moscow: Znanie Publ., 80 p. (In Russ.)
14. Ibragimov, G.I. (2016). About the Role and Place of the Problem-based Learning in the Modern Higher Education. *Alma Mater (Vestnik vysshey shkoly) = Alma Mater (Higher School Herald)*. No. 12, pp. 21-26. (In Russ., abstract in Eng.)
15. Ayyildiz, Y., Tarhan, L. (2018). Problem-based learning in teaching chemistry: enthalpy changes in systems. *Research in Science and Technological Education*. No. 36 (1), pp. 35-54.
16. Ma, X., Pan, Y.-J., Chen, F., Ding, X., Tseng, S.-P. (2018) A constructive problem-based course design for internet of things. *Smart Innovation, Systems and Technologies*. No. 86, pp. 397-402.
17. Shishigu, A., Hailu, A., Anibo, Z. (2018). Problem-based learning and conceptual understanding of college female students in physics. *Eurasia Journal of Mathematics, Science and Technology Education*. No. 14 (1), pp. 145-154.
18. Moody, K., McHugh, M., Baker, R., Cohen, H., Pinto, P., Deutsch, S., Santizo, R.O., Schechter, M., Fausto, J., Joo, P. (2018). Providing Pediatric Palliative Care Education Using Problem-Based Learning. *Journal of Palliative Medicine*. No. 21 (1), pp. 22-26.
19. Khoiry, M.A., Hamid, R., Johari, M.H., Baharom, S. (2017). The efficacy of problem-based project learning method for materials technology course. *Journal of Engineering Science and Technology*. No. 12, pp. 42-49.
20. Veale, C.G.L., Krause, R.W.M., Sewry, J.D. (2018). Blending problem-based learning and peer-led team learning, in an open ended 'home-grown' pharmaceutical chemistry case study. *Chemistry Education Research and Practice*. No. 19 (1), pp. 68-79.
21. Isaev, A.P., Plotnikov, L.V. (2016). «Educational Engineering» in the Context of Implementation of the CDIO Ideology. *Vysshee obrazovanie v Rossii = Higher Education in Russia*. No. 12, pp. 45-52. (In Russ., abstract in Eng.)
22. Conover, W.J. (1999). *Practical Nonparametric Statistics*. New York: John Wiley & Sons.

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Технология подготовки креативных выпускников инженерного бакалавриата

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Аннотация. *Статья посвящена технологиям инженерного образования, позволяющим формировать наиболее востребованные профессиональные качества у выпускников бакалавриата. Сделан обзор исследований в области внедрения инноваций для совершенствования образовательного процесса в практико-ориентированном бакалавриате. Выделены достоинства и ограничения проектной и проблемной технологий обучения. В работе представлен опыт разработки и применения авторской технологии обучения на основе интеграции проблемного и проектного обучения, предназначенной для повышения креативности образовательного процесса в инженерном бакалавриате. Дано её описание, в котором показаны* *механизмы комплексного использования преимуществ методов проблемного и проектного обучения в формировании профессиональных компетенций, необходимых для инновационной деятельности инженера – от проектной разработки до производства нового изделия. Рассмотрены данные эмпирического исследования, на основе которых обоснованы выводы о том, что интеграция проблемного и проектного обучения в виде целостной технологии является эффективным инструментом развития творческих способностей у студентов.*

Ключевые слова: *инженерное образование, проектное обучение, проблемное обучение, интеграция технологий обучения, творческие способности*

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